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# Techno-economic assessment of a solar PV, fuel cell, and biomass gasifier hybrid energy system

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ABSTRACT

The interest of power is expanding step by step all through the world. Because of constrained measure of fossil fuel, it is vital to outline some new non-renewable energy frameworks that can diminish the reliance on ordinary energy asset. A hybrid off-grid renewable energy framework might be utilized to reduction reliance on the traditional energy assets. Advancement of crossover framework is a procedure to choose the best mix of part and there cost that can give shabby, solid and successful option energy resource. In this paper sun oriented photovoltaic, fuel cell, biomass gasifier generator set, battery backup and power conditioning unit have been simulated and optimized for educational institute, energy centre, Maulana Azad National Institute of Technology, Bhopal in the Indian state of Madhya Pradesh. The area of the study range on the guide situated of 23° 12′ N latitude and 77° 24′ E longitude. In this framework, the essential wellspring of power is sun based solar photovoltaic system and biomass gasifier generator set while fuel cell and batteries are utilized as reinforcement supply. HOMER simulator has been utilized to recreate off the grid and it checks the specialized and financial criteria of this hybrid energy system. The execution of every segment of this framework is dissected lastly delicate examination has been performing to enhance the mixture framework at various conditions. In view of the recreation result, it is found that the cost of energy (COE) of a biomass gasifier generator set, solar PV and fuel cell crossover energy system has been found to be 15.064 Rs/kWh and complete net present cost Rs.51,89003. The abundance power in the proposed framework is observed to be 36 kWh/year with zero rates unmet electrical burden.



## 1. Introduction

In a hybrid energy system various electrical energy generators and electrical energy storing device are consolidated together to take care of the electrical power demand of remote and country zone or even an entire group (Khare et al., 2013). Fig. 1. show that standalone PV generators, biomass gasifier, little hydro plants, fuel cell, wind turbine and others wellsprings of electrical energy can be added as expected to take care of the electrical power demand in a way different determines. The motivation behind this paper is the recreation displaying and streamlining of a sunlight based photovoltaic, biomass gasifier generator set and fuel cell hybrid energy system (Singh et al., 2015). It couples a sunlight based photovoltaic generator, biomass gasifier generator set energy component and fuel cell unit to give diverse framework topologies. This framework is proposed to be an earth amicable arrangement since it tries to boost the utilization of a renewable energy source. Photovoltaic generators which straightforwardly change over sun based radiation into electrical energy. A considerable measure of critically favorable position, for example, being in modest and contamination free, quiet with no turning part and with size autonomous electric transformation productivity. From an operation perspective, a PV power era encounters huge varieties in its yield power because of irregular climate conditions. One strategy to conquer this issue is to incorporate the photovoltaic framework with another force source, for example, biomass gasifier generator set, fuel cell, wind power, battery go down and the diesel goes down generator along these lines, as to guarantee a ceaseless 24 h supply. National renewable Energy laboratory's (NREL) hybrid optimization model for electric renewable (HOMER) simulator has been utilized to complete the present study (Bekele and Tadesse, 2012). HOMER performs a relative financial examination on a disseminated era power frameworks. Inputs to HOMER will play out an hourly recreation of each conceivable blend of segments entered and rank the frameworks as per client determined criteria, for example, the expense of energy (COE, Rs/kWh) or capital expenses.

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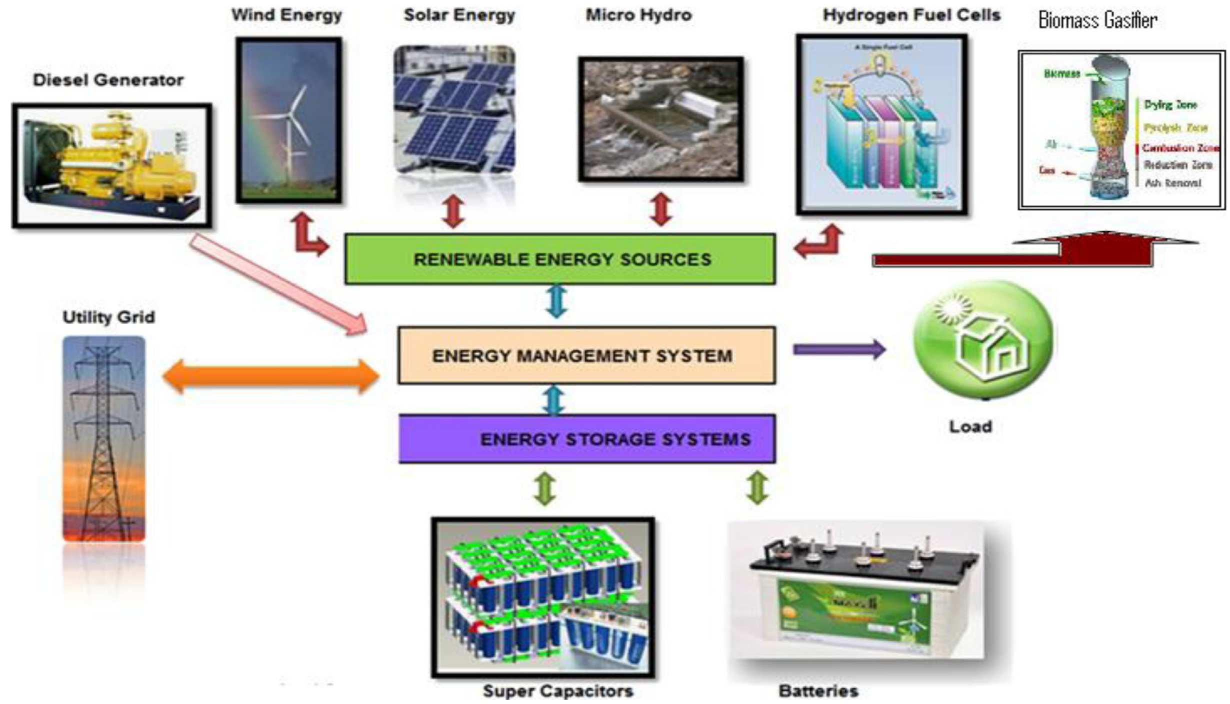


**Fig. 1.** Hybrid energy system (Fathima and Palanisamy, 2015).

## 2. Present renewable energy scenario in India

India is a nation with more than 1.2 billion individuals representing more than 17% of the world's populace. It is the seventh biggest nation on the planet with the aggregate area territory of 3,287,263 km$^2$. India measures 3214 km from north to south and 2993 km from east to west (Garg, 2012). It has an area outskirts of 15,200 km and a coastline of 7517 km. India has 28 states and 7 union domains. The power utilization per capita in India is only 566 kWh. India turned into the world's third-biggest maker of power in the year 2015 with 4.8% worldwide offer in power era surpassing Japan and Russia, however, is still a power shortage nation. Regardless of gigantic development in power generation, the country keeps on confronting both energy and top deficiency (Tripathi et al., 2016). During the 12 months 2014–15, there would be power shortage of 5.1% and peak scarcity of 2.0%. Power shortage is not through any ability the sole issue. Its spread is a similarly primary issue. Previously, the desire of a power asset for power technology was ruled through finding the slightest costly energy developing a plant. Albeit such a methodology is crucial, there is developing worry about different parts of force are such age, social, natural and mechanical advantages and results of the energy source choice (Kumar et al., 2015). Coal has the most extreme a worldwide temperature alteration potential took after by natural gas and others. Further, it should be re-underscored that in India, as most creating nations, the expense of delivering power is of foremost concern while making arrangements for the sort of plant to be introduced and authorized and all the more so with an inexhaustible supply of coal. Nonetheless, over the long haul on the off chance that we produce the results of the poisons on human wellbeing and environment and expense and endeavors expected to enhance or modify the way of debasement, the underlying higher expense of utilizing renewable assets for delivering energy may not be too huge. A high level of alert is additionally required as rising economies like India may not at present have money related assets to jump specifically to cleaner components of energy. Since an earth-wide temperature boost is a global marvel and it has no limits there is a dire requirement for the exchange of innovation and improvement of suitable money related instruments from built up the world to countries who are as yet attempting to locate their legitimate spots. No contention is expected to comprehend that the world is today confronting the issue of an earth-wide temperature boost because of quick industrialization and urbanization took after by the Western world. Regarding per capita value India is 145th on the planet with an arrival of 1.25 ton $CO_2$ for each annum (Khare et al., 2016). The essential hotspots for the generation of power in this nation are coal, fuel, gas and hydro power. Be that as it may, the assets like coal, gas or fuel is not boundless and will not have the capacity to provide food the force prerequisite for mass individuals following a couple of years (Dufo-lópez et al., 2011). This is the reason nowadays India is working for the generation of power from renewable energy sources of nature like a windmill, sun based power, tidal power, biomass and waste material, fuel cell, geothermal energy and so forth. India uses to power from renewable energy sources diminishes the issue of an earth-wide temperature boost (Bernal-agustıet al., 2006).

## 3. Proposed hybrid energy system

A solar photovoltaic energy source should be hybrid with other energy sources, whether used in either a stand-alone or grid-connected mode. Stand-alone energy systems are very popular, especially in remote sites. Fig. 2 show that system under study in this paper is the block diagram of a hybrid energy system, which is constituted of a photovoltaic generator, fuel cell, biomass gasifier generator set, battery, and converter. The development of appropriate simulation tools will help in dealing with modeling, simulation, and design and energy management of the system under study (Hosseinalizadeh et al., 2016). The object of the study is to reach a design that optimizes the operation of a solar photovoltaic, biomass gasifier generator set and fuel cell hybrid energy system.

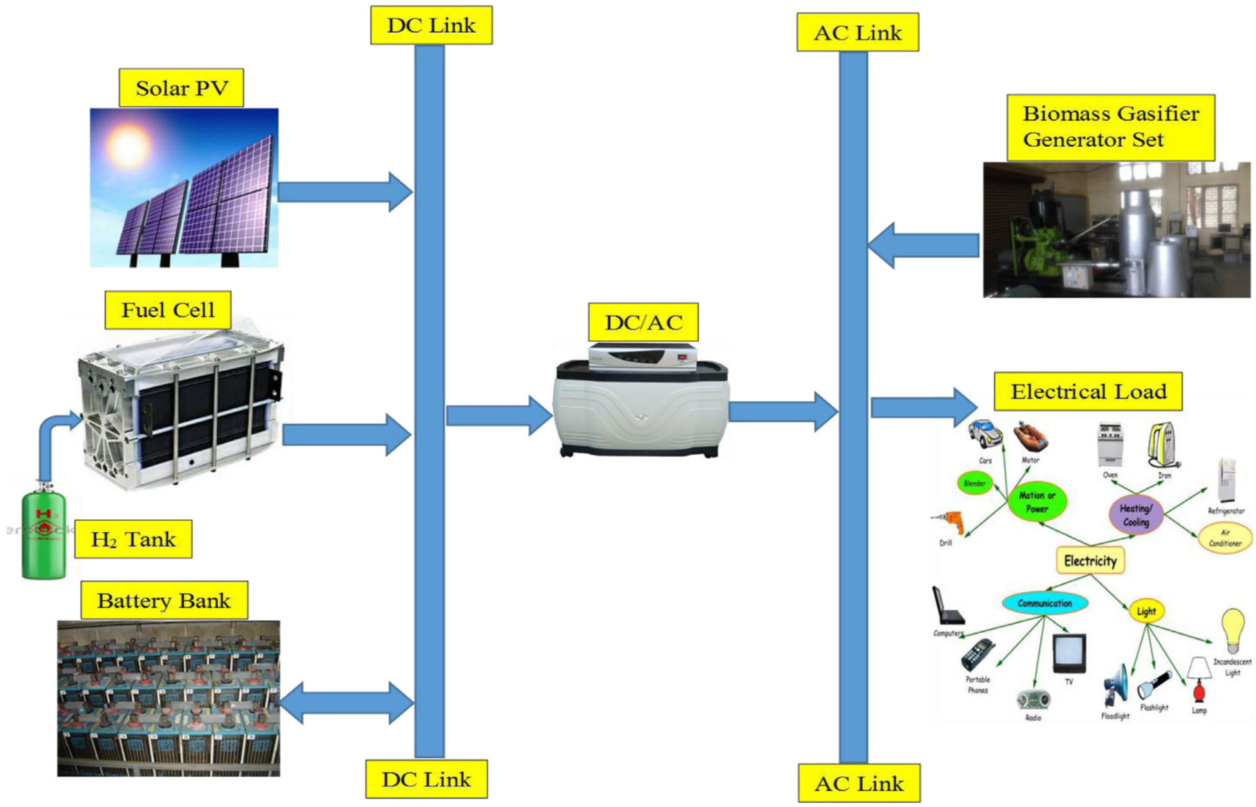


**Fig. 2.** Proposed block diagram of solar photovoltaic, biomass gasifier and fuel cell hybrid energy system.

## 4. Hybrid energy system components description

Hybrid energy system made up of the solar photovoltaic, fuel cell, biomass gasifier, and battery storage. The optimization of the size and cost of the hybrid energy system is very important and leads to a good ratio between system cost and performances.

### 4.1. *Solar photovoltaic system*

Sunlight can be directly converted into electric energy by photovoltaic (PV) panels (Shukla et al., 2016a). The current output of a PV panels a function of voltage and as a function of solar radiation (Shukla et al., 2015). The panel's power output can be found by multiplying the current and the voltage (Kazem and Khatib, 2013). The power supplied by the solar PV panel is calculated by (Hamatwi, 2016)

$$P_{PVout} = P_{NPV} \times \left(G/G_{ref}\right) \times \left[1 + K_T\left(T_C - T_{ref}\right)\right] \quad (1)$$

where; $P_{PVout}$ = Output power from the PV cell, $P_{NPV}$ = rated power at reference conditions,

$G$ = Solar radiation (W/m); $G_{ref}$ = Solar radiation at reference conditions ($G_{ref}$ = 1000 W/m);

$T_{ref}$ = Temperature at reference conditions ($T_{ref}$ = 25 °C), $K_T$ = Temperature coefficient of the maximum power for mono and poly-crystalline Si. $T_C$ = Cell temperature.

A 1 kW solar PV energy system's installation and replacement costs are taken approximately as Rs. 1,50,000/- and Rs. 1,00,000. The lifetime of the solar PV arrays are taken as 20 years and no tracking system is included in the solar PV.

### 4.2. *Fuel cell*

A fuel cell is an electrochemical gadget that converts chemical energy directly into electrical power. Like a battery, an energy component comprises of a couple of terminals and an electrolyte. A fuel cell comprises a polymer electrolyte film sandwiched between two terminals (anode and cathode). In the electrolyte, no one but particles can exit and electrons are not permitted to go through. In this way, the stream of electrons needs a way to an outside circuit from the anode to the cathode to create power on account of a potential distinction between the anode and cathode. Varying operating conditions, the output voltage of fuel cell is (Carapellucci and Giordano, 2012):

$$V_c = V_{rev} - V_{act} - V_{ohm} - V_{conc} \quad (2)$$

where, $V_{rev}$ = Nernst Voltage, $V_{ohm}$ = Ohmic polarization, $V_{conc}$ = Mass transport, $V_{act}$ = Activation polarization.

The cost of fuel cell varies widely depending on scale, power electronics requirements, and reformer requirements. In this paper we assumed fuel cell capital cost 2,00,000 Rs/kW, replacement cost 1,50,000 Rs/kW size varied for 0 to 5 kW (Fuelcellstore, 2016). This study assumed fuel cell lifetime 1500 h.

### 4.3. *Biomass gasifier*

The creation of generator gas (maker gas) called gasification, is the fractional burning of strong fuel (biomass) and happens at temperatures of around 1000 °C. The reactor is known as a gasifier. The burning items from complete ignition of biomass, for the most part, contain nitrogen, water vapor, carbon dioxide and excess of oxygen. However in gasification where there is an overflow of strong fuel (inadequate burning) the results of ignition are flammable gasses like carbon monoxide (CO), hydrogen ($H_2$) and hints of methane and non-helpful items like tar and tidy (Heydari and Askarzadeh, 2016). The power production in the small-scale biomass gasification plants is almost totally made via internal combustion engines (ICE). The overall system electrical efficiency

$\eta_{elc}$ is defined as

$$\eta_{elc} = \frac{P_{out} - P_{aux}}{(Input\ biomass)_{LHV}} \tag{3}$$

$$\eta_{elc} = \frac{P_{net}}{(Input\ biomass)_{LHV}}. \tag{4}$$

$P_{out}$ Represents the electrical power output of the system (as sum of the power produced by the different technologies), while $P_{aux}$ represent the power required by some of the system components, such as compressors, pumps, blowers, electrical generator, etc., if present. So $P_{net}$ represents the effective electrical power that the system can generate. $(Input\ biomass)_{LHV}$ input biomass lower heating value (LHV) MJ/kg (Mckendry, 2002). In this paper we expected energy unit capital cost 96,000 Rs/kW, replacement cost 50,000 Rs/kW size of biomass gasifier generator set 5 kW.

### 4.4. Power converter

In hybrid energy system, the principle segments are power converter. It depends on power electronics devices (Eroglu et al., 2011). A power electronic converter is expected to keep upstream of power between the AC and DC segments. Consider for hybrid energy system 5 kW converter. The capital expense of converter Rs. 15,000/-, substitution cost Rs. 10,000/-. A lifetime of a unit is thought to be 20 years with an efficiency of 90%.

### 4.5. Battery

A battery bank is utilized as a reinforcement system and it likewise keeps up consistent voltage over the electrical load. The battery bank is a conventional way to deal with store electrical power with high effectiveness. Its releasing level cannot surpass a base breaking point characterized as the profundity of release. The storage capacity ($C_{Wh}$) is calculated by (Malheiro et al., 2015)

$$C_{Wh} = (E_L \times AD)\ \eta_{inv} \times \eta_b \times DOD \tag{5}$$

where:

$E_L$ = Total energy demand; AD = Daily autonomy; DOD = Battery's depth of discharge;
$\eta_{inv}$ = Inverter efficiency; $\eta_b$ = Battery efficiency.

The capital cost Rs 50,000/per 1KVA and substitution cost 30,000/- and battery lifetime 4 year.

## 5. Cost analysis

In the cost-advancement strategy, HOMER race reproduces every framework design in the pursuit space and shows the conceivable ones in an outline, sorted by net present cost (Bahramara et al., 2016). Hence it shows a subset of these overall optimization results by displaying only the least-cost configuration within each system category or type (Sigarchian et al., 2015). The cost of the hybrid energy system ($C_{HES}$) becomes the sum of the cost of its individual components i.e. solar PV system cost ($C_{SPV}$), fuel cell cost ($C_{PEMFC}$), biomass gasifier cost ($C_{BG}$), battery cost ($C_{BAT}$), electrolyzer cost ($C_{ELECTO}$), power converter cost ($C_{PCON}$) and hydrogen tank cost ($C_{HTANK}$).

$$C_{HES} = C_{SPV} + C_{FC} + C_{BG} + C_{BAT} + C_{ELECTO} + C_{PCON} + C_{HTANK}. \tag{6}$$

Cost of each component of hybrid energy system,

$$C_i = N_i \times [CapC_i + (Re\,C_i + NR_i) + OMC_i] \tag{7}$$

where,

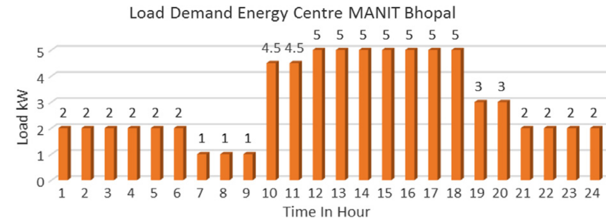


**Fig. 3.** Load demands energy centre MANIT Bhopal for a day.

$i$ = Component of the hybrid energy system (solar PV/fuel cell/biomass gasifier/power converter/electrolyzer/hydrogen tank), $N_i$ = Number/Size of hybrid energy system component, Cap$C_i$ = Capital cost hybrid energy system component, Re$C_i$ = Replacement cost hybrid energy system component, NR$_i$ = Number of replacements. OMC$_i$ = Operation and maintenance cost hybrid energy system component. HOMER first evaluates the specialized achievability of the framework and whether it can take care of the load demand. Second, it appraises the aggregate net present cost (NPC) of the framework, which is the life-cycle expense of the framework, including the initial set-up costs (IC), part replacement costs (RC), operation and maintenance costs (OM), fuel costs (FC), and the acquiring power costs (PC) from the network. HOMER simulator net present cost (NPC) by the accompanying equation (Li et al., 2013).

$$C_{NPC} = \frac{C_{AT}}{CRF\,(i_r P_L)} \tag{8}$$

$$CRF = \frac{i_r(1+i_r)^N}{(1+i_r)^N - 1} \tag{9}$$

where, $C_{NPC}$ = Net Present Cost, $C_{AT}$ = Total annualized cost, $CRF$ = Capital recovery factor, $P_L$ = Project life (20 years), $i_r$ = Real interest rate (6.3%), $N$ = Number of years (Maatallah et al., 2016).

## 6. Load demands for proposed area

The selected proposed area of an educational institute, energy centre, Maulana Azad National Institute of Technology (MANIT), Bhopal in the Indian state of Madhya Pradesh (Bijarniya et al., 2016). The location of the study area on the map located off 23° 12′ N latitude and 77° 24′ E longitude. Energy centre MANIT Bhopal the basic load is required to use electrical appliances like Tube light, ceiling fan, experiment setup, computer, and machinery (Shukla et al., 2016b). The energy load demands in the morning and night, the hour is small. Load demand to 8 h from 10:00 to 6:00 approximant high as compared morning and night hour. In this study 5, kW has been considered to scale peak load. AC primary load demand shown in Fig. 3.

## 7. Simulation model

The simulation model has been designed HOMER Pro software and consists of a biomass gasifier, solar, fuel cell, battery and electrolyzes (Sigarchian et al., 2015). There are sources of energy in this system: solar PV, biomass gasifier, and fuel cell. A fuel cell is operated when there is a lack of power generated by the solar PV system and biomass gasifier. Hydrogen tank for the utilization by the fuel cell. Although the battery is an energy storage device, it acts as a source of energy when the load demands additional energy which cannot be satisfied by the two main sources. The system architecture of this hybrid energy system is shown in Fig. 4.

**Table 1**
Total net present cost analysis of proposed hybrid energy system.

| *Component* | Capital (Rs) | Replacement (Rs) | O&M (Rs) | Fuel (Rs) | Salvage (Rs) | Total (Rs) |
|---|---|---|---|---|---|---|
| *Solar PV array* | 750,000 | 0 | 3,232 | 0 | 0 | 753,232 |
| *Fuel cell* | 1,000,000 | 1,518,612 | 566 | 0 | −23,956 | 2,495,222 |
| *Biomass gasifier generator set* | 480,000 | 727,366 | 7,287 | 183,893 | −44,119 | 1,354,427 |
| *Trojan IND23-4V* | 200,000 | 88,262 | 5,171 | 0 | −28,203 | 265,230 |
| *Converter* | 75,000 | 21,214 | 12,928 | 0 | −3,993 | 105,149 |
| *Electrolyzer* | 128,000 | 42,427 | 129 | 0 | −7,985 | 162,571 |
| *Hydrogen tank* | 48,000 | 0 | 5,171 | 0 | 0 | 53,171 |
| *System* | 2,681,000 | 2,397,881 | 34,484 | 183,893 | −108,255 | 5,189,003 |

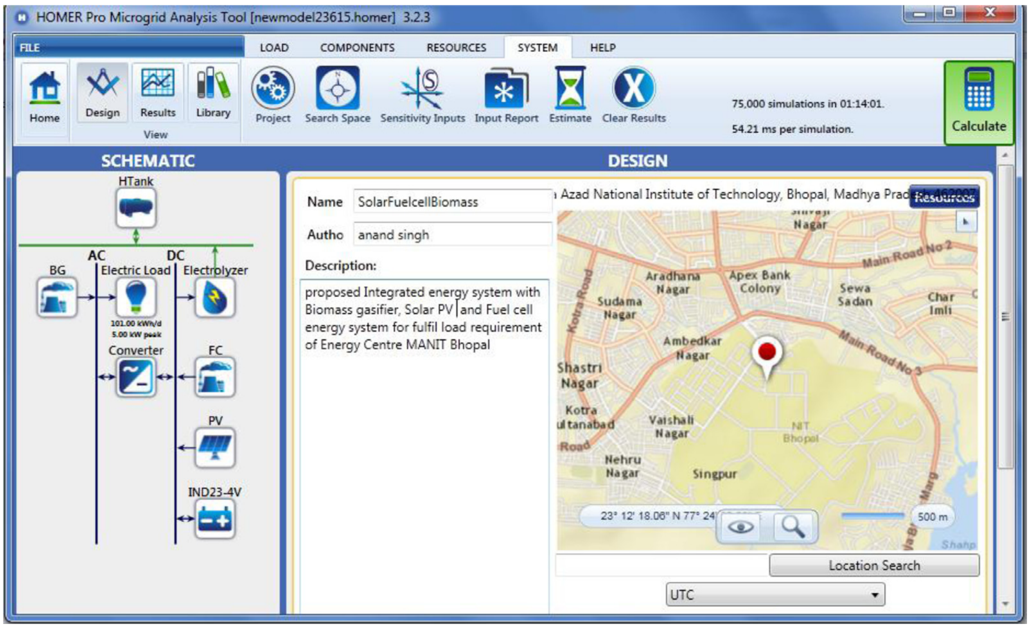


**Fig. 4.** HOMER simulation model of solar PV, biomass gasifier generator set, and fuel cell hybrid energy system.

## 8. Simulation results

This section presents the results analysis of our proposed system. As per the above-given input parameters and constraints, simulation has been carried out using HOMER pro software (Kazem et al., 2013). HOMER pro simulates each blend framework arrangement in hunt space and sorts the feasible ones based on the aggregate net present cost (NPC) and the required power demands a given zone under its available energy resources. The optimal combination of hybrid energy system components for our case study is an energy source solar photovoltaic capacity has been allowed to vary 0 to 5 kW. Fuel cell power has been considered to change from 0 to 5 kW. Biomass gasifier generator sets 5 kW, 24 Trojan IND23-4V Batteries, 5 kW converter with a dispatch strategy of cycle charging. Table 1 shows the cost of the various components in the proposed system total net present cost (NPC), capital cost (CC) and the cost of energy (COE) for such a hybrid energy system are Rs. 51,89003, Rs. 2,681,000, and 15.064 Rs/kWh, respectively.

The average consumption of the AC primary load is 27,625 kWh per year. The monthly average electricity production of the solar PV system, fuel cell, and biomass gasifier is shown in Fig. 5. It can be seen that the power production of the solar PV system is 8481 kWh/year, fuel cell power production is 7300 kWh/year and Biomass gasifier generator set power production is 13,957 kWh/year. Total power production of the hybrid energy system is 29,738 kWh per year. The biomass gasifier contributes about 46.93%, solar PV 28.52% and the fuel cell 24.55%.

Fig. 6 Shows the AC primary load profile of energy centre, MANIT Bhopal (48 h). Solar PV electrical power output (48 h),

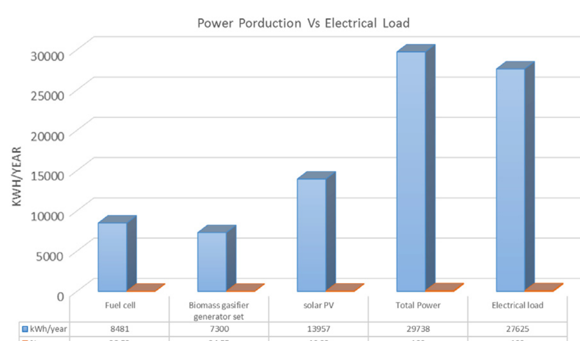


**Fig. 5.** Electrical power production sharing by solar PV, biomass gasifier generator set and fuel cell.

biomass gasifier generator set electrical power output (48 h), and fuel cell electrical power output (48 h).

Power shared by each of the sources as well as the battery along with the AC input power fed to an inverter and the load power during a typical day have been shown in Fig. 7. When sufficient solar power is available during the daytime, the load is directly supplied by the solar PV system and biomass gasifier available during the daytime. Biomass gasifier supplies the power at night hour when load demands high during this time period, whenever the power exceeds the load power, the excess power is used in charging the battery and as seen from the Fig. 7. When solar and biomass power is unavailable the fuel cell feeds the load and charges the battery during the time periods from night 9:00 AM to morning 4:00 AM. When power not available from

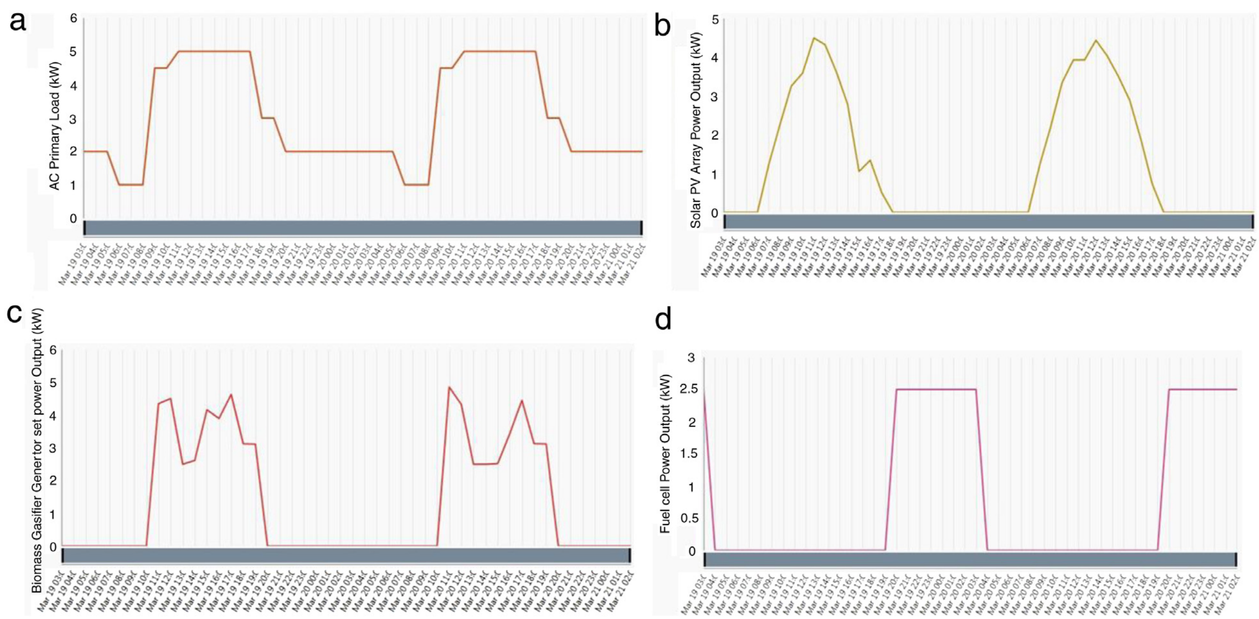


**Fig. 6.** (a) AC primary load profile of energy centre, MANIT Bhopal, (b) Solar PV power output, (c) Biomass gasifier generator set power output (d) Fuel cell power output.

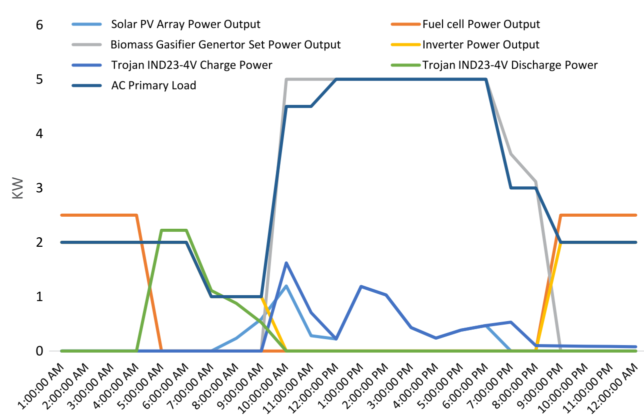


**Fig. 7.** Power shared by the components of the hybrid energy system for a day.

renewable energy source, then the battery delivers power and meet the load demand (Gangwar et al., 2015) presented the hybrid energy system combination of solar PV, wind and fuel cell for lecture building. In this hybrid system unmet electrical load of 6.11 kW/year and excess of electricity 27,023 kWh/year and (Site et al., 2014) capacity shortage 2% where as in our proposed system, the optimal sizing of the components is selected having an unmet electrical load of 0%, capacity shortage 0% and excess of electricity 36 kWh/year.

## 9. Conclusion

In this paper considered accessible local energy resource and augmenting the utilization of renewable energy assets. A solar PV, biomass gasifier generator set, & fuel cell hybrid energy system for electrical power supply at energy centre MANIT Bhopal have been carried out using HOMER pro software. The outcomes got from the HOMER programming give various options achievable hybrid systems with various levels of renewable assets entrance which their decision is limited by changing the net present expense of every setup. The cost of energy (COE) of a hybrid energy system has been found to bé 15.064 Rs/kWh and total net present cost (NPC) Rs. 51,89003. The results of the proposed system clearly validate that with the optimized sizing of 5 kW biomass gasifier generator set, 5 kW solar PV, 5 kW fuel cell. The optimal sizing of the components is selected for an unmet electrical load of 0%, capacity shortage 0% and excess of electricity 36 kWh/year. The hybrid system will be able to feed the varying load requirement in all the seasons without any power interruption.

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